PROCEDURES FOR HVAC SYSTEM DESIGN AND INSTALLATION

The goal for a HVAC system is to provide proper air flow, heating, and cooling to each room. This page sets out key criteria that describe a quality system, and key design and installation considerations that should be met to achieve this goal. The pages following contain more detailed information on design, fabrication, installation, and performance testing.

Criteria for a Quality HVAC System

An HVAC system should:

1. Be properly sized to provide correct air flow, and meet room-by-room calculated heating and cooling loads;
2. Be installed so that the static air pressure drop across the handler is within manufacturer and design specifications to have the capacity to meet the calculated loads;
3. Have sealed supply ductwork that will provide proper air flow;
4. Be installed with a return system sized to provide correct return air flow;
5. Have sealed return ductwork that will provide proper air flow to the fan, and avoid air entering the HVAC system from polluted zones (e.g., fumes from autos and stored chemicals, and attic particulates);
6. Have balanced air flows between supply and return systems to maintain neutral pressure in the home;
7. Minimize duct air temperature gain or loss between the air handler and room registers, and between return registers and the air handler;
8. Be properly charged with refrigerant;
9. Have proper burner operation and proper draft.

Procedures to Design and Install an Air Distribution System

The following steps should be followed in the design and installation of the HVAC system to ensure efficiency and comfort (for details, see Appendix 1):

1. Determine room-by-room loads and air-flows using ACCA Manual J calculation procedures (or substantially equivalent);
2. Layout duct system on floor plan, accounting for the direction of joists, roof hips, fire-walls, and other potential obstructions. Determine register locations and types, duct lengths, and connections required to produce layout given construction constraints;
3. Size duct system according to ACCA Manual D calculation procedures (or substantially equivalent);
4. Size HVAC equipment to sensible load using ACCA Manual S procedures (or substantially equivalent);
5. Install equipment and ducts according to design specifications, using installation requirements and procedures from the Uniform Mechanical Code, the Air Diffusion Council, SMACNA, California Residential Energy Efficiency Standards, and manufacturers' specifications (Title 24); Using these procedures and those in Appendix A, the duct system should be substantially air tight;
6. Charge the system appropriately, and verify charge with the evaporator superheat method or subcooling method (or substantially equivalent);

7. Check for proper furnace burner operation and fire-box drafting;
8. Test the system to ensure that it performs properly by determining (1) that the system is properly sized, (2) it does not leak substantially, and has either (3a) proper air handler fan flow, and proper plenum static pressures, or (3b) proper room and return air flows, and proper plenum static pressures. (Procedures are detailed in Appendix A.)

APPENDIX 1

Recommended Details for an HVAC System:
Materials, Fabrication, Design, Installation, and Performance Testing

MINIMUM MATERIALS SPECIFICATIONS

The following are minimum materials specifications recommended to achieve a substantially tight installation that will last:

<u>All Materials</u>

- Shall have a minimum performance temperature ratings per UL181 (ducts), UL181A (closure systems for rigid ducts), UL181B (closure systems for flexible ducts) and/or UL 181BM (mastic);
- Shall have a flame spread rating of no more than 25 and a maximum smoke developed rating of 50 (ASTM E 84);

<u>Factory-Fabricated Duct Systems</u>

- All factory-fabricated duct systems shall include UL 181 listed ducts with approved closure systems including collars, connections and splices;
- All pressure-sensitive and heat-activated tapes used in the manufacture of rigid fiberglass ducts shall be UL 181A listed;
- All pressure-sensitive tapes and mastics used in the manufacture of flexible ducts shall be UL 181B (tape) or UL 181BM (mastic) listed.

<u>Field-Fabricated Duct Systems</u>

- Ducts:
  - Factory-made ducts for field-fabricated duct systems shall be UL 181 listed.
- Mastic sealants and mesh:
  - Sealants shall be UL 181BM listed, non-toxic, and water resistant;
  - Sealants for interior applications shall pass ASTM tests C 731 (extrudability after aging) and D 2202 (slump test on vertical surfaces);
  - Sealants and meshes shall be rated for exterior use;
  - Sealants for exterior applications shall pass ASTM tests C 731, C 732 (artificial weathering test), and D 2202.
- Pressure-sensitive tapes:
  - Pressure sensitive tape shall be that recommended by and meet the requirements of the flexduct manufacturer;
  - Tape used for duct board shall be UL 181A listed and so indicated with a UL 181A mark or aluminum-backed butyl adhesive tape (15 mil. minimum).
- Drawbands:
  - shall be either stainless-steel worm-drive hose clamps or uv-resistant nylon duct ties;
  - shall have a minimum performance temperature rating of 165 degrees Fahrenheit (continuous, per UL 181A-type test) and a minimum tensile strength rating of 50 pounds;
  - shall be tightened as recommended by the manufacturer with an adjustable tensioning tool.

DESIGN, FABRICATION, AND INSTALLATION

The following are design, fabrication, and installation guidelines, that, if carefully followed, will provide a duct installation that is substantially airtight:

General Issues

- Ducts, plenums, and fittings should be constructed of galvanized metal, duct board, or flexible duct. Building cavities may not be used as a duct or plenum without a sealed duct board or metal liner.
- The air handler box should be air-tight;
- Air filters should be easily accessible for replacement, and evaporator coils should be easily accessible for cleaning;
- Ducts should be configured and supported so as to prevent use of excess material, prevent dislocation or damage, and prevent constriction of ducts below their rated diameter;
- Flexible duct bends should not be made across sharp corners or have incidental contact with metal fixtures, pipes, or conduits that can compress or damage the ductwork;
- Sheet metal collars and sleeves should be beaded to hold drawbands.

DESIGN HVAC SYSTEM

<u>Loads and CFM Calculation</u>

- ACCA Manual J Load Calculation or equivalent required;
- Calculate heat loss and heat gain for each room;
- Total room loads to determine system requirements.

<u>Lay Out Air Distribution System</u>

- Lay out duct system on floor plan and determine register positions and duct paths to optimize room air circulation and minimize duct length;
- Duct paths must account for locations and directions of joists, roof hips, fire walls, and other potential obstructions;
- Duct paths must be planned to avoid sharp turns of flexduct that will kink the duct.

<u>Size Air Distribution System</u>

- ACCA Manual D Duct Design or equivalent required;
- Calculate correct cfm for each room and total for building for both supply and return;
- Size ducts according to Manual J loads, Manual D air flows, and final layout on plans;
- Choose registers to optimize air distribution and duct static pressure;
- Size and locate returns to optimize air flow per Manual D;
- For return-filter grills, calculate minimum return filter area per Manual D.

<u>Select System</u>

- ACCA Manual S Residential Equipment Selection or equivalent required. ACCA, 1515 16th St., NW, Washington, DC 20036, (202)483-9370;
- From Manual J loads and Manual D cfm, determine appropriate equipment
- Equipment should be sized to sensible loads;
- Equipment sensible capacity should not be more than 15% larger than the total sensible design load (as specified in Manual S).

FABRICATE AND INSTALL AN AIRTIGHT DUCT SYSTEM

All Duct Types

- All joints and seams of duct systems and their components should be sealed with mastic, mastic and embedded mesh, or pressure-sensitive tape approved for use by the duct manufacturer and meeting UL181 specifications ("approved tape"); this includes around junctions of collars to distribution boxes and plenums;
- All sealants should be used in strict accordance with manufacturer's installation instructions and within sealants moisture and temperature limitations;
- All tapes used as part of duct system installation should be applied to clean, dry surfaces and sealed with manufacturer's recommended amount of pressure or heat. If oil is present, taped surfaces should be prepared with a cleaner / degreaser prior to application;
- It is recommended that all register boxes should be sealed to the drywall or floor with caulking or mastic.

Flexible Ducts

- Flexible ducts should be joined by a metal sleeve, collar, coupling, or coupling system. At least 2 inches of the beaded sleeve, collar, or coupling must extend into the inner core while allowing a 1 inch attachment area on the sleeve, collar, or coupling for the application of tape;
- The inner core should be mechanically fastened to all fittings, preferably using drawbands installed directly over the inner core and beaded fitting. If beaded sleeves and collars are not used, then the inner core should be fastened to the fitting using #8 screws equally spaced around the diameter of the duct, and installed to capture the wire coil of the inner liner (3 screws for ducts up to 12" diameter, and 5 screws for ducts over 12" diameter);
- The inner core should be sealed to the fitting with mastic or approved tape;
- Tape used for sealing the inner core should be applied with at least 1 inch of tape on the duct lining, 1 inch of tape on the fitting of flange, and wrapped at least three times;
- The outer sleeve (vapor barrier) should be sealed at connections with a drawband and/or three wraps of approved tape;
- The vapor barrier should be complete. All holes, rips, and seams must be sealed with mastic or approved tape.

Metal Ducts and Plenums

- Metal-to-metal connections should be cleaned and sealed in accordance with manufacturer's specifications;
- Openings greater than 1/16 inch should be sealed with mastic and mesh, or butyl adhesive tape;
- Openings less than 1/16 inch should be sealed with mastic or UL-181A listed tape;
- Special attention should be paid to collar connections to duct-board and/or sheet metal; seal around the connection with mastic;
- Connections between collars and distribution boxes should be sealed with mastic or approved tape;
- At least three equally-spaced #8 screws should be used to mechanically fasten round ducts (3 screws for ducts up to 12" diameter, and 5 screws for ducts over 12" diameter);
- Crimp joints should have a contact lap of at least 1_ inches;
- Square or rectangular ducts should be mechanically fastened with at least one screw per side.

Duct Board

- Duct board connections should be sealed with adhesive, mastic, or UL 181A listed pressure-sensitive or heat-activated tape in accordance with manufacturer's specifications.

Duct Support

- Supports should be installed per manufacturer's specifications or per UMC requirements;
- Supports for flexible ducts should be spaced at no more than 4 foot intervals;
- Flexible ducts should be supported by strapping having a minimum width of 1_ inches at all contact points with the duct;
- Supports should not constrict the inner liner of the duct;
- Flexible ducts should have maximum of _ inch sag per foot between supports;
- Flexible ducts may rest on ceiling joists or truss supports as long as they lie flat and are supported at no more that 4 foot intervals.

<u>Boots</u>

- After mechanically attaching the register boot to floor, wall, or ceiling, all openings between the boot and floor, wall, or ceiling should be sealed with caulk or mastic.

<u>Seal Air Handler</u>

- Openings greater than 1/16 inch should be sealed with mastic and mesh, or butyl adhesive tape;
- Openings less than 1/16 inch should be sealed with mastic or UL 181A listed tape;
- Unsealed access doors should be sealed with UL 181A listed tape.

CHECK REFRIGERANT CHARGE

- For systems with fixed metering devices use evaporator superheat method:
  - indoor coil airflow must be <u>greater</u> than 350 cfm/ton;
  - refrigerant system evacuation must be complete (all non-condensables must be removed from the system;
  - in hot, dry climates be cautious to be within range of superheat charging chart or use a different method.
- For systems with thermostatic expansion valves use the subcooling method.

CHECK COMBUSTION PERFORMANCE

- Check each chamber for correct flame;
- Check for proper drafting.

TEST SYSTEM PERFORMANCE

The following are testing requirements and procedures that must be followed to ensure that the HVAC system has been properly installed. The tests are designed to determine whether:

1. *Room-by-room air flows are correct;*
2. *Total supply is as designed;*
3. *Total return = total supply;*
4. *Ducts, plenum, and air handler are tight;*
5. *Static pressure is correct.*

- Test the system to ensure that it performs properly, by (1) verifying HVAC equipment sizes installed are those specified, (2) measuring duct leakage, and measuring either (3a) fan flow or (3b) supply and return flows and plenum static pressures:
  1. Air conditioner sensible capacity must be no more than 15% greater than the calculated sensible load; fan flow must be greater than 350 cfm/ton; check that the correct size air handler is installed.

2. Ensure that the duct system does not leak substantially:
   a. A rough system, including both supply and return but without the air handler, should not leak more than 0.03*conditioned floor area (ft_) per system measured in cfm @ 50 Pa;
   b. The finished installation, including supply, return, the air handler and finished registers, must not leak more than 0.07*conditioned floor area (ft_) per system measured in cfm @ 50 Pa;

3a. Measure air handler air flow and static pressure across fan; ensure that total air handler output is within 5% of design and manufacturer specifications at a static pressure within 0.1 in wg of design.

3b. Supply and return air flow, and static pressure requirements: Ensure that supply and return flows are correct, and that the static pressure across the fan is correct:
   a. Measure room-by-room air flows to ensure that each register is within 15% of Manual D design air flow, and that the entire supply is within 5% of design;
   b. Measure return air flow to ensure that it is within 5% of the total supply air flow;
   c. Test static pressure drop across the blower to ensure that it is within 0.1 in wg of design and manufacturer specifications.

- Duct leakage can be determined using a pressurization or depressurization technique; for details, see Minneapolis Duct Blaster™ manual, or other commercially available duct pressurization or depressurization devices;
- Duct leakage to unconditioned space can be determined with the house pressurization or LBL simplified technique; for details see CEC report P400-91-031CN, Section Six;
- Fan flow, supply flow and return flow measurements, see Minneapolis Duct Blaster™ manual (or equivalent); alternatively for supply and return flows, use a calibrated flow hood. Do not use a pitot tube, or any type of anemometer to determine these air flows;
- Static pressure drop across the fan is measured using a small probe in the return plenum and in the supply plenum.

PROBLEMS WITH ACCEPTED PRACTICE SIZING METHODS:

Relationship Between Duct System Performance, ACCA Design Procedures, and Installed-System Quality

Background

The Air Conditioning Contractors of America (ACCA) association publishes four manuals related to residential heating and air conditioning that address many of the issues associated with residential duct systems. ACCA Manual J (Load Calculation for Residential Winter and Summer Air Conditioning, Copyright 1986) is the industry-standard design-load calculation procedure for residences. ACCA Manual S (Residential Equipment Selection, 2/92) provides procedures for choosing residential heating and cooling equipment based on the loads calculated with Manual J. ACCA Manual D (Residential Duct Systems, Copyright 1995, 2nd Printing) provides design procedures for residential duct systems, focusing on how to produce the desired air delivery at each register, as well as discussions of the magnitudes and impacts of duct-system inefficiencies. ACCA Manual T (Air Distribution Basics for Residential and Small Commercial Buildings, UPB592-10M) addresses room air motion issues, focusing on the impacts of register/grille location and diffuser performance.

Treatment of Duct Performance in ACCA Manual J

ACCA Manual J addresses residential duct system performance in three ways: 1) it provides room-by-room loads, which are intended to be used to calculate the energy that needs to be transported by the ducts to each room, 2) it provides a table of duct-loss multipliers that are used to calculate the extra design load associated with conduction losses from the ducts, and 3) it provides a table of recommended levels of duct insulation, and states that “All ducts should have their seams sealed with tape”.

In calculating the energy load impacts of ducts and room-by-room loads, Manual J makes two fundamental assumptions: 1) that there is no duct leakage, and 2) that the load due duct conduction is independent of the length and design of the ducts. The implication of the first assumption is that the actual load associated with duct losses is in general significantly higher than that assumed in Manual J. The second assumption implies that even if the average conduction losses in the duct-loss multipliers are correct, the calculated room-by-room loads are incorrect due to non-uniform conduction losses.

A significant body of research performed over the past five years in California and other states that install ductwork in attics and crawlspaces demonstrates that duct leakage increases space-conditioning energy use by 15-20% on average, even in new construction. This loss needs either to be eliminated, or to be added to the losses associated with conduction gains to obtain correct loads seen by the equipment. Field research has also demonstrated the effective increase in heating and cooling system capacity associated with improving duct performance (Modera and Jump, 1995). Those studies show reduced fractional on-times and increased cycling under the same weather conditions after duct retrofit.

A logical question that arises with respect to these duct leakage losses is why Manual J is not resulting in significantly undersized systems because of the fact that it does not include these duct leakage losses. The reasons for why this is not the case seem to stem principally from the application of Manual J, rather than the manual itself. In general, Manual J leaves quite a bit to the discretion of the user, leaving numerous opportunities for increasing the size of the unit. Some of the common points at which safety margins seem to creep in are:

- The use of the worst house orientation for load calculations,
- The choice of the next size up in the piece of heating/cooling equipment,
- The assumption of 50% RH indoor conditions in most manufacturer's capacity data, which is higher than what is found in much of California, and which results in a lower estimated sensible capacity for a piece of equipment as compared to the sensible capacity the equipment would have at a lower indoor humidity level,
- Using a somewhat lower indoor design temperature,
- Using a higher outdoor design condition, such as 1%, or utility-peak outdoor design temperature rather than the 2.5% values recommended in Manual J.
- Using the next-highest outdoor-temperature rating point, rather than interpolating manufacturer's capacity data.
- The recommendation of 0-15% oversizing of sensible capacity in Manual S.

To be fair, it should also be noted that there are some factors that tend to decrease the size of the equipment chosen with the ACCA procedures, including:

- ARI capacities are normally quoted at 80^{o}F, whereas Manual J requires capacities at 75^{o}F, which will be smaller.

It is very difficult to quantify exactly how much the above trends influence equipment sizing. A contractor survey performed in Florida indicated that there is a large variability in the equipment-sizing practices used by contractors (Home Energy 1995). It is safe to say that there are numerous opportunities for a contractor to increase equipment size within the ACCA procedures so as to maintain the sizing with which they are comfortable. A related study of equipment sizing and ACCA manuals is published in Home Energy magazine (Proctor et al. 1995).

The assumption of constant duct-loss multipliers for all duct sections (or in other words, that duct loads scale with room load, and not with duct design or length) is more of a design-flaw and comfort problem, rather than an energy-use or equipment-sizing problem. Namely, after calculating room-by-room loads including constant duct-loss multipliers, the air flow required for each room is calculated from the loads, the duct system is laid out, and the cross-sectional area of the ductwork is calculated and checked with Manual D based upon the ability of the system to supply the required air flow. This implies that the percentage energy loss from the longest duct run is the same as that from the shortest run. It seems clear that this is not a realistic assumption, however the magnitude of the resulting disparity, based upon field measurements, is striking. Namely, the bedroom closest to the furnace for an R-4 duct system in a Sacramento attic was measured to have 12% of the duct energy lost by conduction on the way to the register. The equivalent losses for the master bedroom at the end of the duct run were more than 40% (Modera and Jump, 1995). The 12% loss is line with the losses that are calculated from the Manual J duct loss multipliers, and the 40% loss clearly indicates that the master bedroom duct is most likely undersized. Sure enough, the homeowner commented on the improvement in master-bedroom conditions after the retrofit. The end result of this disparity is that the entire duct-design process is skewed so as to provide far less than optimal distribution of heating and cooling.

There is another assumption within Manual J that is likely to result in inaccurate estimates of room-by-room loads. Namely, it is assumed that the infiltration load is split between rooms based on the estimated relative external leakage area of that room. The problem with this assumption is that it ignores the fact that a significant fraction of residential air infiltration is driven by the stack effect. The implication of ignoring the stack effect in two-story houses is that in general the upstairs flows will be oversized for heating, resulting in unnecessary stratification and discomfort in the winter. This upstairs-duct oversizing should actually help reduce stratification in the summer.

In addition, it is also worth noting that the duct loss multipliers for an attic and a crawlspace are the same, which is clearly inconsistent with intuition and field experiments. The result is that cooling equipment with attic ductwork is likely to be relatively undersized as compared to cooling equipment with crawlspace ductwork.

Treatment of Duct Performance in ACCA Manual D

As noted above, the principal function of Manual D is to assure that a given duct layout delivers the appropriate air flows to each room, based upon the room-by-room loads calculated with Manual J. Thus, if the total load seen by the duct run to a given room is not correct, the size of the ductwork leading to that zone will not be correct, resulting in poorly designed system (i.e., one that does not provide uniform heating or cooling, and which is difficult or impossible to balance).

There is however a disconnect within Manual D. Namely, Manual D contains an entire, fairly complete section on duct-system energy efficiency, however this section is not connected to the load calculation procedures used to size the equipment and ductwork.

Treatment of Duct Performance in ACCA Manual T

As noted above, Manual T focuses on the room-air motion aspects of air distribution systems. The way that this relates to duct performance and quality HVAC installations is through the performance of the diffusers. In particular, if a diffuser is designed to provide a given throw at a specific air flow rate, that throw will be reduced (potentially significantly) by supply-duct leakage or by flow restrictions within the ductwork (e.g., flexduct that is not fully extended, that is bent at hangers, or that is bent at too sharp of a radius).

Recommended Strategy for California

Based upon the discussion above, a two-phase strategy for improving the quality of HVAC installations is recommended. The first phase of the strategy simply addresses the issue of duct leakage, focusing on the interaction between duct leakage and equipment sizing with Manual J and Manual S. The second phase addresses the quality of the design, focusing on a methodology for accurately laying out and sizing ductwork so as to provide better occupant comfort.

The essence of the Phase-I strategy is to develop a modification to Manual J duct loss/gain multipliers that takes into account duct leakage losses, and to combine this with an appropriate training course designed to help contractors take some of the oversizing trends out of their Manual-J calculations.

The essence of the Phase-II strategy is to address the duct-design problems in the combination of Manual J and Manual D. This can be accomplished by inserting an overall duct-loss calculation procedure for each register in the house into the process. This may require some iteration between the duct-sizing procedure and the duct-loss calculation procedure, however one or two iterations will most likely be adequate, and the final design will not only provide better comfort, but should ultimately result in better energy efficiency. This overall duct-loss calculation procedure should most-likely be based on the simplified procedure developed by Palmiter (1995) that is likely to be adopted into the proposed ASHRAE Standard 152P. This procedure should be used separately for heating and cooling operation.

REFERENCES

1991 Uniform Mechanical Code (UMC) Sections 1002 - 1005 and Appendix A, Standard No. 10-5.
Air Diffusion Council, Flexible Duct Performance & Installation Standards.
ACCA Manual J, Seventh Edition, 1986
ACCA Manual D, New Edition, 1995

ACCA	1515 16th St., NW, Washington, DC 20036, (202)483-9370
ASTM E 84	Test for Surface Burning Characteristics of Building Materials
ASTM C 731	Extrudability After Aging
ASTM C 732	Artificial Weathering Test
ASTM D 2202	Slump Test on Vertical Surfaces
SMACNA Manual	Installation Standards for Residential Heating and Air Conditioning Systems
UL Standard 181	Standard for Factory-Made Air Ducts and Air Connectors
UL Standard 181A	Standard for Closure Systems for Use With Rigid Air Ducts and Air Connectors
UL Standard 181B	Standard for Closure Systems for Use With Flexible Air Ducts *(in progress)*
UL Standard 181BM	Standard for Mastic Materials

ACCA substantial equivalents:

ASHRAE	1791 Tullie Circle, N.E., Atlanta, GA 30329, (404)636-8400